DEVELOPMENT OF CUBELAB FOR PLANT MICROGRAVITY RESEARCH

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Master of Science

by

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Accepted by the faculty of the College of Science and Technology, Morehead State University, in partial fulfillment of the requirements for the Master of Science degree.

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Using new CubeLab technologies provided by Space Tango to enhance Exomedicine research, the primary focus of research is on the effects of microgravity in early stage plant growth. The experimental design will provide desirable system conditions for installation aboard the ISS, within Space Tango's research platform. *Catharanthus roseus* plant seeds possess unique cell cycle inhibitors, commonly known as vinca alkaloids. These compounds are heavily used in chemotherapy drug synthesis. These seeds will be placed aboard the ISS prior to any seedling growth or plant development. Upon return, these compounds will undergo analysis to determine if microgravity exposure yielded an increase of compound abundance. The system is designed to conduct research of interest, while in parallel proving the system viability for continued experiments that could utilize the system. The Tube-Cube system will house, stabilize, and manage

the experimental environment. The Bus will be required to manage command and data handling. The research platform aboard the ISS will provide power and data communications between Earth and the ISS. Additional experiments are expected to follow to draw conclusions, in pursuit of new cancer treatment options.

Accepted by: ________________________________, Chair
Dr. Benjamin Malphrus

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Robert Twiggs

Acknowledgments

I would like to thank everyone who helped me along this trying journey. A special thanks to Dr. Ben Malphrus, who continually guided my path through this program. I could not have completed this project without the support of Dr. Malphrus and Jeff Kruth. Thank you Professor Kruth for serving as my thesis director, and for continually providing support and guidance to ensure my success. All the opportunities which I gained from the Space Science Center were all truly wonderful. I would also like to give my upmost gratitude for Mrs. Jen Carter, for allowing me to grow as an educator and for continually serving as a mentor to me. To Space Tango Inc. and the University of Kentucky School of Pharmacy, thank you for granting me the opportunity to work on this experiment. Lastly, thank you to Professor Robert Twiggs for always having such positive energy and profound passion for Exomedicine research. I am so glad our paths crossed and I am grateful to have you as a committee member.

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Chapter I: Introduction

Advancements in science require large time commitments and frequently yield minimal results. Medical science advancements are commonly taken as a high priority item, as a means to better human life as we know it on Earth. Daily diseases take the lives of individuals at all ages, the most common of these being cancer. To date, in 2016 1.6 million new cases of cancer have been diagnosed (Society, Cancer Facts & Figures 2016, 2016). Advancements in cancer research are a high priority item with increasing incident rates yearly. Members of the Kentucky based Exomedicine Institute have founded their research on the belief that "What if the next big breakthrough in medicine isn't on Earth?" (Exomedicine Institute, n.d.). This statement derived the coined term, Exomedicine. Exomedicine is the study and exploration of medical solutions leveraging the microgravity environment of space.

The space environment exhibits many different conditions than the traditional environment here on Earth. The two most commonly identified factors are the free-fall or "zero-gravity" environment in addition to the harsh radiation environment. In history every time humans have harnessed a new physics environment, innovations have been created (SpaceTango, 2016). Using this idea, the Kentucky based company SpaceTango has founded their company on pursuing this new environment. SpaceTango works to provide more accessible methods to continue Exomedicine research.

Statement of the problem

The space environment exhibits a harsh radiation environment along with the presence of microgravity. This environment offers a platform for unique research. Based on the known effects it has on human health, from observations of astronaut response, this environment presents interesting unexplained biomedical phenomenon. The difference of human health in space is a concern for astronaut well-being, but it also is pertinent to civilian life.

Astronauts are required to maintain a healthy lifestyle as well as be in peak physical health. Greater interest emerges about the effects of the space environment on physical health not in peak condition, such as human cells which are effected by disease or cancer. It is possible the environment could increase, decrease or have no effect on these human cells. The conditions which space provides allow for potentially life-changing possibilities.

Cancer is a disease which consumes many lives every year, and a disease which grasps the attention of many. Treatment options for chemotherapy typically yield undesirable effects: hair loss, nausea, anemia, etc. These effects are all results of the inability to target cancer cells specifically. Treatment methods only target rapidly dividing cells which include hair and blood cells.

There are two goals of this experiment: a biomedical goal and an engineering goal. The biomedical goal is to determine if microgravity exposure during early stages of plant development alters chemotherapy compounds in later stages of development. The engineering goal of this thesis is to design and fabricate a means of containment for the biomedical payload.

Significance of the study

The plant compounds of interest during this experiment are vinca alkaloids. These compounds inhibit the synthesis phase of the cell cycle, which further prohibits the occurrence of cell division. The compounds are produced from the pink periwinkle plant *Catharanthus roseus*, commonly referred to as Madagascar periwinkle (Moudi, Go, Yien, & Nazre, 2013). The plant is a flower bearing plant, however the compounds of interest are contained within the leaves. These compounds are the oldest plant alkaloid group that is used to treat cancer (Moudi, Go, Yien, & Nazre, 2013). These compounds are extremely common in combination chemotherapy treatment options.

These compounds have proven to provide an excellent source for cancer treatment. Microgravity has been proven to induce changes which are not replicable in Earth conditions. The experiment was designed to determine whether changes occur in vinca alkaloids while in microgravity conditions. Should changes occur, they may provide new opportunities for cancer treatment.

Assumptions

This experiment was developed to be housed inside the TangoLab, an autonomous space station module. The design produced as a result of this work will be used to send the defined experiment to the ISS. The launch date for this experiment will occur after the conclusion of the academic year. TangoLab is a research framework which allows for low-cost, microgravity research opportunities to be pursued. The payload will contain samples of the periwinkle seeds along with a secondary payload seed genus type, Valeriana. This genus is also a flower bearing plant with a different mechanism of action. The payload will return to Earth at the completion of the mission for extensive analysis after orbit. The experiment will be identified as the PeVaLab, resulting from the two seed type names.

The TangoLab will be housed aboard the International Space Station (ISS). The ISS does provide protection against the harsh radiation environment. This will eliminate any opportunity for alterations in results due to the radiation environment. Containing the experiment aboard the ISS permits control of environmental external variables. This experiment will improve our understanding of how these compounds are affected when exposed to the microgravity environment of space.

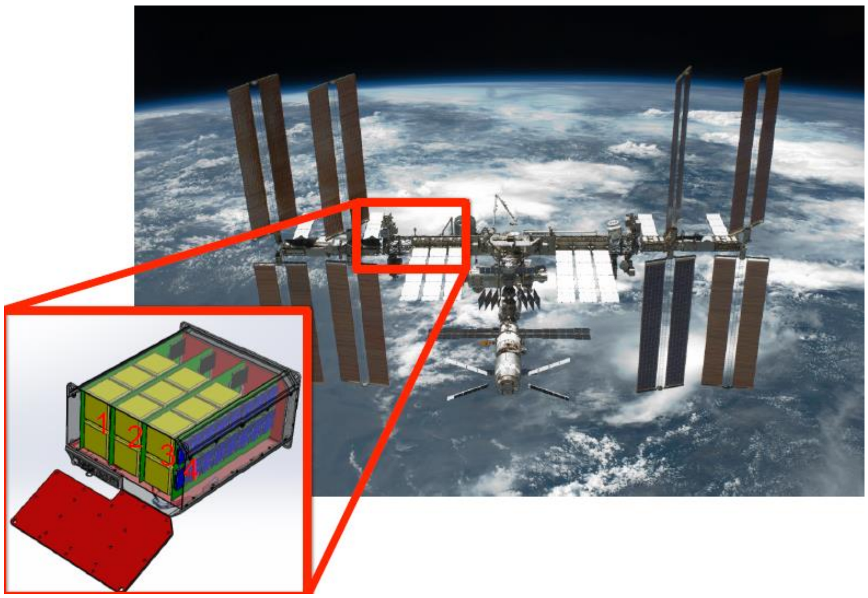

Figure 1-CAD Drawing of TangoLab's location aboard the ISS

Figure 2-TangoLab with associated hardware

Limitations

When designing an experiment were it is necessary for technology to be flown on the ISS, extra precautions must be taken to ensure all requirements are met. The main limitation in this design is the time constraint. This design needs to be finished prior to the completion of the academic year, in preparation for a June 2016 launch date. This design must be compatible with the TangoLab system and must have the proper implementations to carry the biological payload.

Definition of terms

CAD – Computer Aided Design is software used to create high precision drawings and illustrations. This software can be used to create two-dimensional or three-dimensional drawing.

CubeSat – A CubeSat is a satellite made from a cube measuring ten centimeters in length, weighing no more than 1 kg per cube. Cubes can be combined, using combinations of smaller units to form larger satellites. Each one-kilogram unit with a length of ten centimeters is referred to as a 1U, or one unit. Typically, these satellites range between 1U and 3U in size, for interplanetary study 6U CubeSat's are becoming common. These satellites are mostly launched as secondary or tertiary payloads with larger missions. This form factor was designed to fit into areas which balancing weight was typically stowed in a rocket. By placing small satellites into this area this provided an educational opportunity for students to build and launch satellites (CubeSat, n.d.).

ISS – The International Space Station is found above Earth's atmosphere in low-earth orbit. The space station has been occupied with humans since November 2000. Since then, 222 people from 18 different countries have called this place their home. This orbiting platform provides many opportunities for breakthroughs which cannot occur here on Earth (NASA: Brian Dunbar, 2016).

NEN – The Near Earth Network, formerly known as the Ground Network, provides ground services to a large range of customers. The NEN provides services to satellites in low-earth orbit, geosynchronous orbit, lunar orbit, and missions with multiple frequency bands. Customers do include international customers, along with many national. Even more, the NEN provides services to government and commercial affiliates. The NEN is operated by the NASA Goddard Space Flight Center in Maryland (NASA, 2016).

Parafilm – This substance is a film with a paper backing commonly used for sealing vessels. This film is ductile, malleable, waterproof, translucent, and odorless. This film can be used to protect containers against contamination and moisture. The film is known to degrade after long exposure to air and light, therefore it is not commonly used as a long term method of sealing.

Space Tango Inc. – This company was created to provide full service solutions to microgravity research. Space Tango works to streamline and simplify the process for using microgravity, which allows for scalable experimentation. Space Tango consistently works to utilize the unique environment of microgravity to discover, design and commercialize solutions for applications on Earth (SpaceTango, 2016). This company is currently located in Lexington, Kentucky.

TDRSS – The Tracking and Data Relay Satellite System is a satellite network made up of nine satellites, and found in geosynchronous orbit. The system was created with the primary goal to provide continuous services to NASA's most critical low earth-orbiting missions. The need for continuous availability was driven by the effort to rely less on international ground stations and the opportunity to create highly available communication coverage (Menrad, 2014).

Chapter II: Relevant Technical Issues

Background

Space Tango Inc. has worked to develop methods to limit astronaut involvement for biological payloads on the ISS. Astronauts cost approximately 2.6 billion dollars a year to keep alive in space for one year, that’s 1.25 million dollars an hour (Nosanov, 2015). When experiments aboard the ISS require astronaut time they can become expensive. To minimize astronaut involvement, a module was created which provided an autonomous platform to house various types of research experiments. Space Tango Inc. created the TangoLab which houses small experiments and provides a stable environment with real time access to researchers.

The ISS has been used as a platform for plant research for many years. The environment provides great insight to how plants respond to gravity, informed the design of advanced plant growth facilities, achieved the completed life cycle, and demonstrated that physiological processes necessary for biological life support are sustainable (Stutte, Monje, & Wheeler, 2015). All of this knowledge is significant in understanding the opportunities space provides for life above Earth’s atmosphere. Although vast amounts of plant research have been done on the ISS, minimal records have been located for similar research.

Gravitropism is the function most commonly studied in microgravity, however some metabolic energy processes have been studied. Lastly, secondary metabolites such as vinca alkaloids have previously been shown to have higher concentrations in microgravity than on Earth (Anderson, 2015). Difficulty was found when identifying which stage of growth these experiments occurred at.

Biomedical Overview

Cancer

Cancer is a name given to a collection of related diseases (What is Cancer?, 2015). Individuals who have cancer have a condition in which some of the cells within their body began dividing indefinitely, with no termination point. The dividing cells can result in tumor formation, or in worse cases spread into nearby tissues. This continuous dividing can begin anywhere in the body, and if the rapidly dividing cells divide into moving tissue, such as blood, the cancer can spread throughout the body.

In normal body conditions, when cells become damaged new cells are formed to replace them. The new cells will then take the place of damaged cells. However, when cancer forms this process does not work as expected. The old, damaged cells will not degrade to allow for the newly produced cells. The cells will continually produce and in an abundance may form growths called tumors.

Cancerous tumors are continuously dividing and can spread and invade nearby tissue. This can cause tissue invasion throughout the body, resulting in multiple tumors away from the original tumor site. Tumors which specifically divide and invade other tissue are referred to as malignant tumors. Individuals can have tumors which are benign. These tumors can be removed and do not frequently grow back. Malignant tumors commonly regrow and form new cancerous tissue.

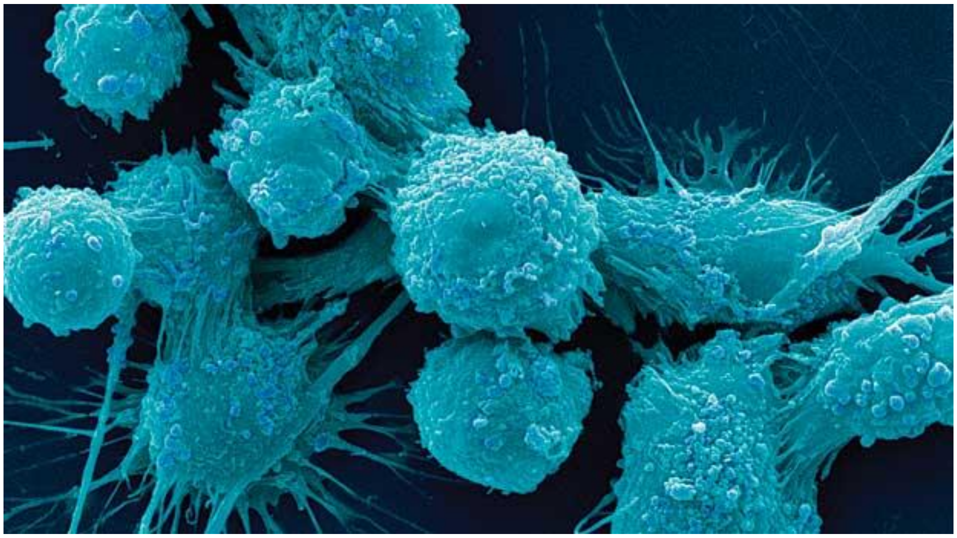

Figure 3-Human prostate cancer cells

Incidence

Cancer is a disease which is a global concern. It is estimated that in United States during 2016, 1.6 million new cancer cases will be diagnosed (Society, Cancer Facts & Figures 2016, 2016). Aside from the newly diagnosed, estimates state that over half a million individuals will lose their lives due to cancer in 2016. In the United States, cancer is ranked second for diseases known to cause death. It falls second to heart disease by approximately thirty-thousand individuals a year (Leaded Causes of Death, 2016). Globally, in 2012 over 14 million people were diagnosed with some form of cancer (Society, Global Facts & Figures 3rd Edition, 2012).

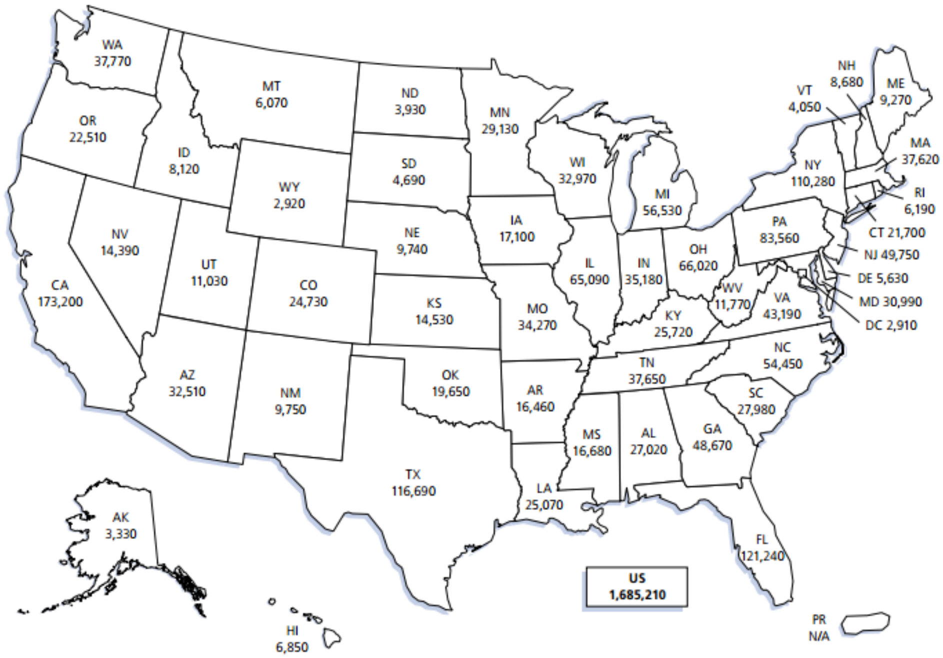

Figure 4-Estimated numbers of new cancer cases for 2016 by state

Treatment

When an individual is found to have a cancerous tissue, the treatment process typically begins immediately. The process can be rather lengthy depending on the type of cancer the individual has and how advanced the tissue has developed. No two individuals' treatment plans are the same, they each are determined based on the person's condition. The two most common treatments include surgery and chemotherapy. While there are other forms of treatment which are used, only the two most common will be discussed here. Treatment forms are commonly used in combination, and rarely used in isolation.

Chemotherapy

Chemotherapy is typically the first method of treatment when an individual is diagnosed with cancer. Chemotherapy kills or slows the growth of rapidly dividing cells (National Cancer Institute, 2015). Rapidly dividing cells are not all cancerous, such as cells that line your mouth and intestine. Chemotherapy often yields undesirable side effects because of the unintended cells which are affected. This form of therapy often precedes any additional forms of treatment.

Surgery

Surgery is a more invasive method to treat cancer, however medical advancements have continued to allow this treatment to become less invasive to patients. Each treatment plan various depending on the severity, therefore each person's surgery will differ slightly. Surgery can work in three main ways to fight cancer: remove the tumor entirely, de-bulk the tumor, or ease cancer symptoms (National Cancer Institute, 2015).

Biological Sample

Catharanthus roseus is the sample chosen for this experiment, this plant is more commonly known as Madagascar periwinkle. *C. roseus* is indigenous to Madagascar, and in traditional forms of medicinal treatment this plant treated a variety of illnesses. Amongst the treatments, it was found that it served as a "rainforest cure for cancer" (Royal Botanic Gardens, Kew, n.d.). After determining that this plant had desirable outcomes for cancer, lab testing was done to determine what made this plant of value. As a result of testing, it was found that the plant contained valuable alkaloids. The alkaloids work to disrupt the cell division process. With the ability to stop the process of cell division, cancer was able to be treated. The alkaloid group which proved to be of greatest interest was found to be called vinca alkaloids (Moudi, Go, Yien, & Nazre, 2013).

Figure 5-Catharanthus roseus bush

The International Space Station: A laboratory for biomedical research

The international space station was developed and determined to be a resource which would provide a “World Class” environment for microgravity research (Penley, Shcafer, & Bartoe, 2002). The space station promotes a stable environment for experiments to be performed. The availability of this platform allows research to be completed more regularly by researchers across the globe. The downfall of this environment is the cost and accessibility to space, these factors typically are what limit a project. Continued efforts are being done to allow an increased availability to and from the space station. Companies such as Space Tango Inc. are working to provide more economic modules within the station to perform microgravity research.

Simulated microgravity

Research in true microgravity is limited due to the limited accessibility of space. Various microgravity simulators have been created as a means to replicate the events which occur in space. These simulators however can never eliminate the one-g force of gravity which is exhibited anywhere on Earth. The only place to find such conditions on Earth are by dropping items from tall buildings, however then these conditions only last for seconds. While each simulator provides different environments, no results have been comparable to those demonstrated in space (Christianen, et al., 2013). Three examples of microgravity simulators are described below.

Clinostats

A clinostat is designed to provide continual rotation to the system contained inside to prevent it from perceiving the gravitational acceleration vector. Various types exist so that you can alter the number of rotation axes, the speed, and the direction of rotation. While this simulator proved to be somewhat effective, the slow continual rotations were found to cause disturbances at the ultrastructural level (Christianen, et al., 2013). These disturbances were not found when the same biological sample was placed in true microgravity.

Random Positioning Machine

The random positioning machine is very similar to a clinostat. Under the assumption that the quality may be enhanced if the system were rotated on two axes instead of one, the random positioning machine was invented. These are also known as 3-D clinostats, because of the two independently rotation axes. These machines are commonly used for larger experiments (Christianen, et al., 2013).

Rotating Wall Vessel

Rotating wall vessels are commonly referred to as rotating bioreactors. These vessels were developed mostly for cell culturing. This device is a Plexiglas cylinder with a central core mounted on a horizontal plane. The central core is mounted on a shaft and connected to a variable speed motor (Christianen, et al., 2013). The speed of rotation varies based on the type of cells or experiment enclosed.

Real Microgravity

Microgravity is commonly used synonymously with the term “free-fall.” This environment exists because of Earth’s gravitational field exhibited on the orbiting body. The ISS is bound in orbit because of Earth’s gravity, and the ISS is directly affected while in orbit. As the ISS orbits around the Earth, it can also be thought of as falling around the Earth (NASA, 2015). The horizontal velocity is great enough that the ISS is traveling outward faster than it is being pulled back toward the Earth. When an astronaut drops an item on the ISS, or even themselves, they are “falling” around the Earth at the same speed as the ISS. This is why astronauts continually appear to be floating within the ISS. The free-fall environment is of interest to researchers because they can then study biological processes in the absence of the persistent 1g force of gravity we feel here on Earth.

Chapter III: Design Tradeoffs

Introduction

The initial design for the PeVaLab was developed by Space Tango Inc. The design had a previously identified experiment incorporated by Space Tango Inc. The experiment is centered around vials which will contain 1000 seeds total. The seeds will be contained in four total vials; all vials will then be contained in one CubeLab. The initial design only used four vials; however, the later design was developed through this thesis is for eight vials. This will allow the design to be used in the future for other experiments. The CubeLab will contain two vials of Madagascar periwinkle seed and two vials of an additional seed type, not discussed within the contents of this paper. The CubeLab design also contains a data logger which is produced by SpaceTango. This data logger will be housed in an end of the cube. It also serves as the attachment point for the cube within the TangoLab.

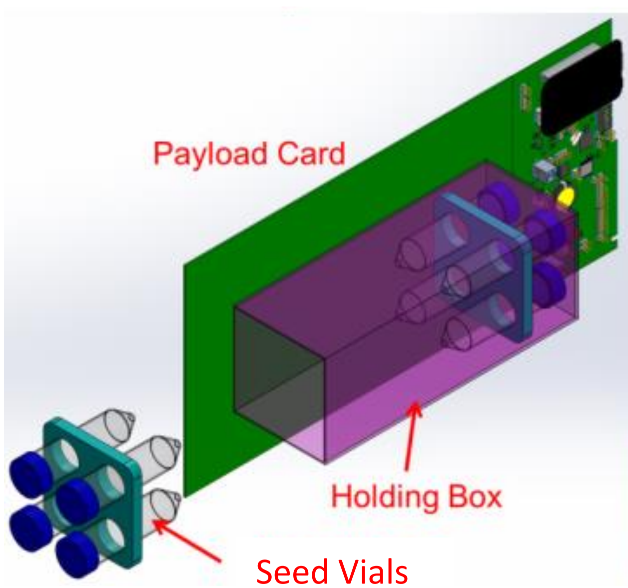

Figure 6-A preliminary CAD model of a CubeLab containing vials

TangoLab Platform

The TangoLab platform was created by Space Tango Inc. to provide a way to reduce astronaut involvement with biological experiments aboard the ISS. Reducing the involvement of astronauts lowers cost and complexity, making this platform more economic than existing equipment. Space Tango Inc. created this lab to house smaller experiments and allows them to run synonymously, also providing real time access to researchers on Earth. The platform automates many critical biological processes commonly executed by humans in a laboratory. The platform is housed in an Express Rack locker within the P1 truss of the ISS.

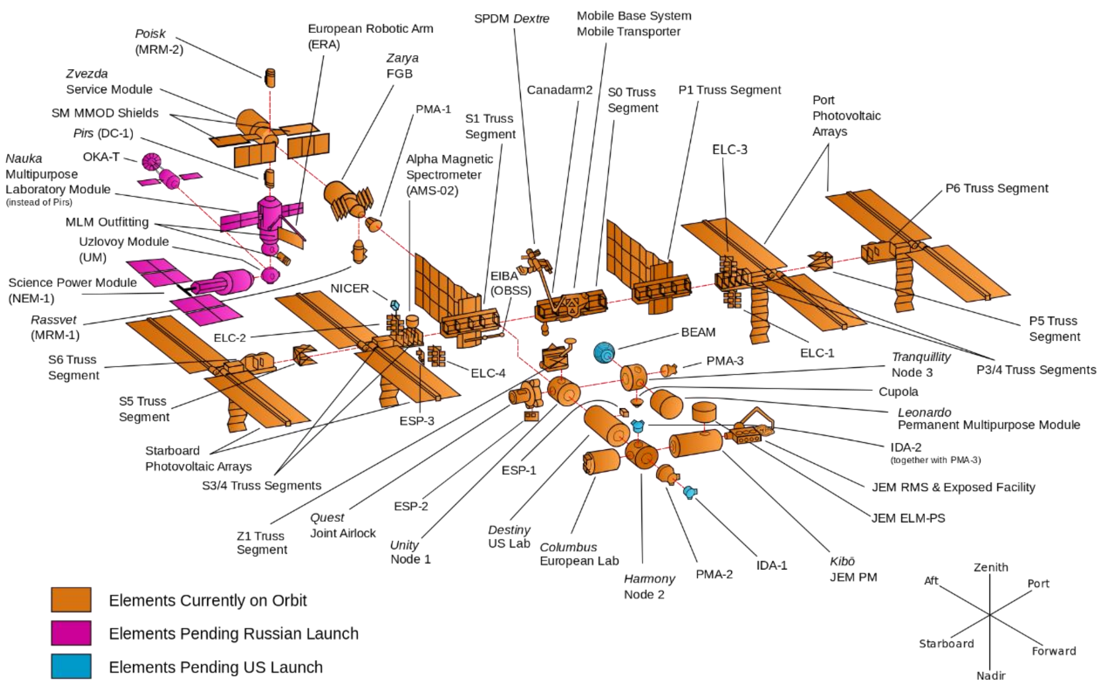

Figure 7-Current ISS configuration (as of May 2015)

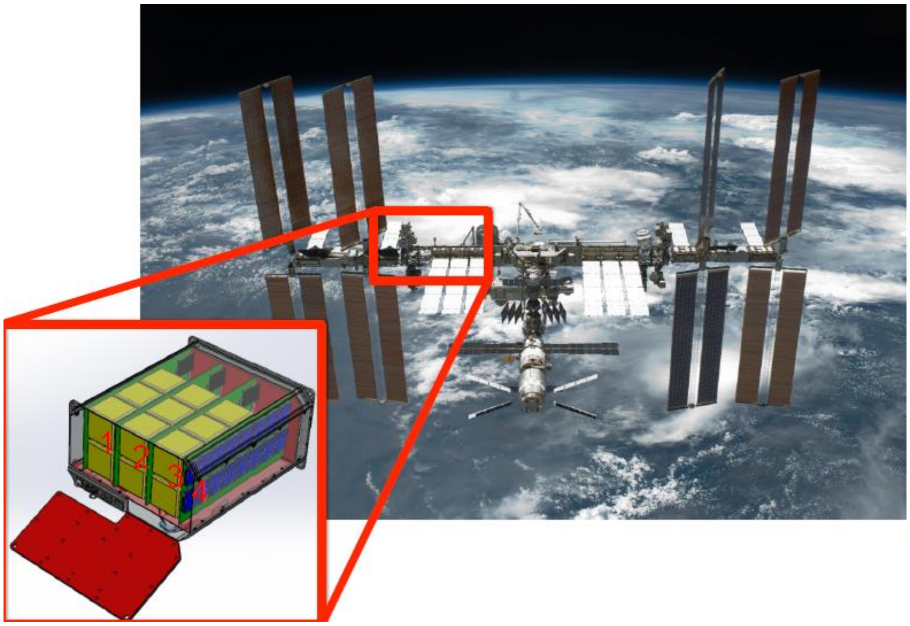

Figure 8-TangoLab positioning on the ISS

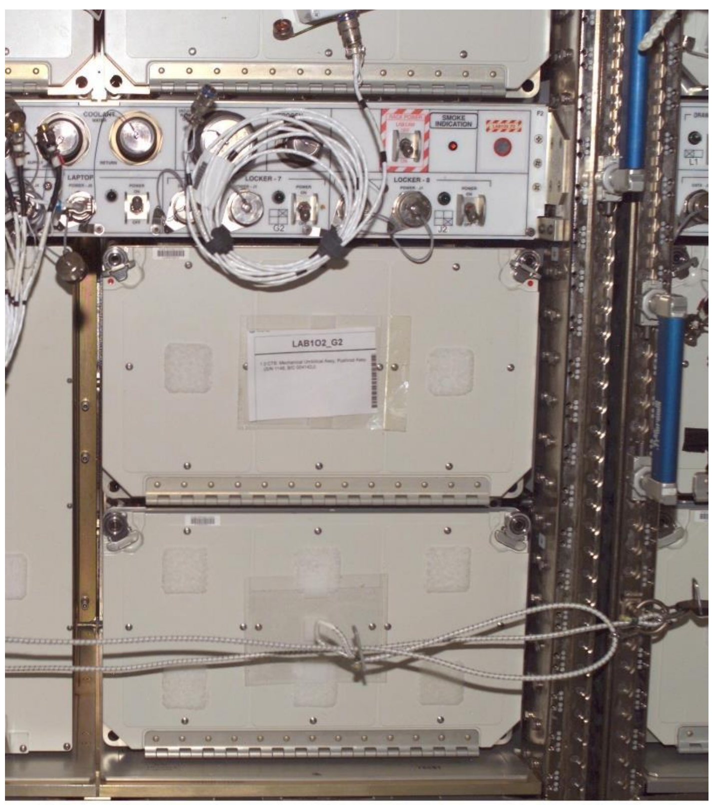

Figure 9-Two Express Rack modules on the ISS

Experimental Platform

A CubeLab is derived from the commonly used CubeSat standard. This standard utilizes the small form factor to identify a universal use within the TangoLab platform. CubeLab's differ slightly from the traditional CubeSat, in that the design requirements differ. CubeSat's are free floating satellites which in turn require onboard power systems and communication systems. CubeLab's are confined within the ISS and will leverage the platforms power and communications systems.

The CubeLab differs slightly from the CubeSat in the placement of the feet on the lab. The CubeLab foot placement is to allow for installation into the TangoLab. A CubeLab has feet on the base of the lab only, opposed to feet on both ends like the CubeSat. The overall size of the CubeLab is slightly different from the CubeSat. The development of the CubeLab provides a standard for performing research in microgravity. The design has now allowed for experiments to be repeated at a regular interval. The standardization will now allow researchers to perform more regular research on a predictable timeline and budget.

The design was initially proposed as a 2U CubeLab which would contain four conical tubes. The cube was drawn as a CAD model, which provided an accurate illustration of space inside the cube. CAD models are not easily attained and extensive time was committed to achieve the experience needed to complete the drawing. Once this drawing was completed, discussion was held and determined that there was a large amount of open space unused within the cube. Access to space is expensive and difficult, so it was undesirable to allow this substantial amount of unused volume remain as part of the design. While the experiment could have been reduced to a 1U CubeLab and used different tubes, it was decided to continue with the 2U design. As a means to reduce the un-used volume, computer modeling illustrated that eight vials could comfortably fit within the 2U cube. The design of a 2U cube containing eight conical tubes has further implications which allow Space Tango Inc. to reuse the arrangement. As this company pursues additional customers, this form factor can be marketed to reduce the customers' expenses.

Dimensions

The dimensions of the CubeLab vary based on the experiment. A one-unit CubeLab is defined as 4.072" X 4.0" X 4.262". Depending on the experiment requirements a combination of this unit can be assembled. In the case of the PeVaLab, a two-unit (2U) CubeLab will be used. The dimensions of this lab are 8.150" X 4.0" X 4.262".

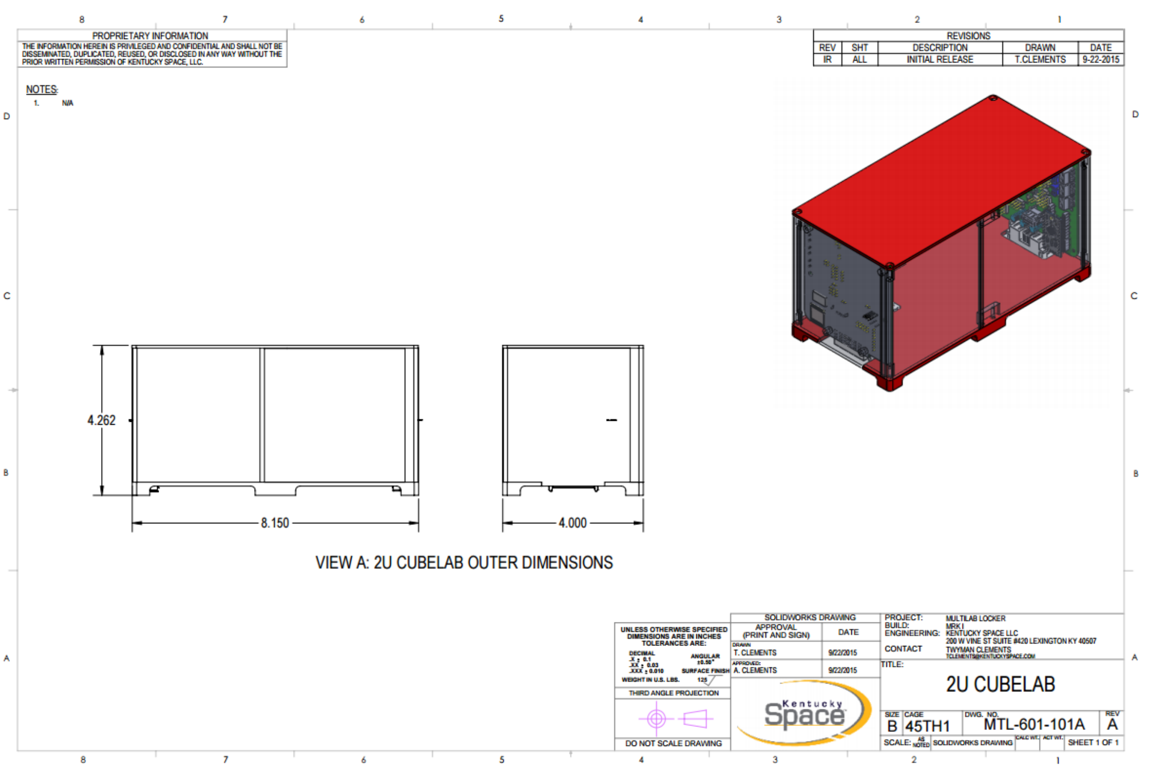

Figure 10-Dimensions specification sheet for a 2U CubeLab

Additional time was spent in discussion with the science principal investigator to ensure all biological requirements were defined and addressed properly. As an outcome of these discussions, the structure of the system remained in the most simplistic form of a CubeLab. The labs do offer various forms of the structure to accommodate different experimental conditions, none of these various forms were needed.

Two experimental platforms will be assembled, one to serve as a control on earth and one to provide experimental data on orbit. These cubes will be assembled identically and synonymously. A control is needed to draw conclusions for any alterations while aboard the ISS. All contributions were discussed in detail with the CEO of Space Tango Inc. to ensure these decisions would be feasible for the company and within the budget allotted.

Biological System

The biological system which will be contained in the CubeLab will be 1000 *C. roseus* seeds. These seeds will have been completely dehydrated and therefore will not have experienced any growth. The seeds will remain dormant throughout the entire mission. These seeds will undergo all analysis after return to Earth. The analysis protocol is not completely defined at this time; the protocol is defined by the researchers’ lab. Space Tango Inc. is not responsible for analysis, only for ensuring the platform is suitable to conduct the researchers experiment.

Chapter IV: Design Implementation

Engineering Design

The CubeLab design was modified slightly from the preliminary conceptual design presented above. The initial design was intended to contain only four vials; however, it was decided to design for eight vials to allow reuse of the design. All electronics within the cube will be contained at the ends of the structure. The electronics are positioned in this way for integration into the TangoLab.

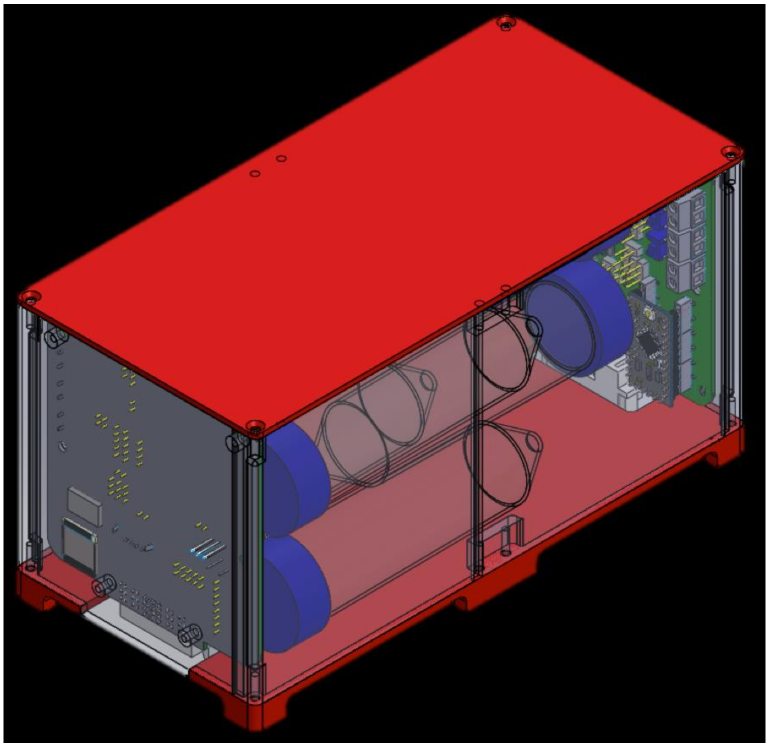

Figure 11-CAD model of PeVaLab design containing four vials

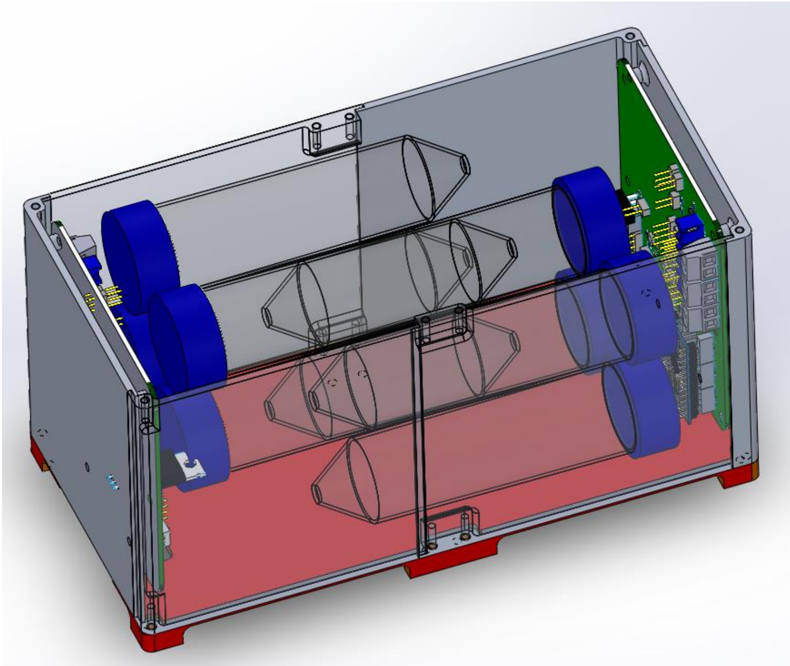

Figure 12-CAD model of CubeLab with eight vials

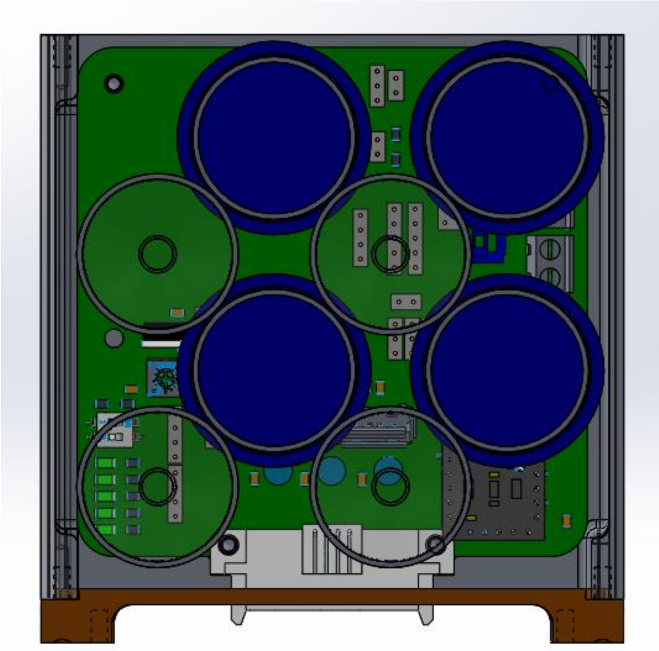

Figure 13-Cross sectional view of CubeLab with eight vials

The vials required some support to minimize shifting during transportation to the ISS. The support was designed to insert thin aluminum brackets into the cube, and each bracket will support four vials. To ensure stability at the center of the cube, a small amount of adhesive material will be used to secure all vials to each other. Between the vials some absorbent material will be placed to minimize damage from a neighboring vial.

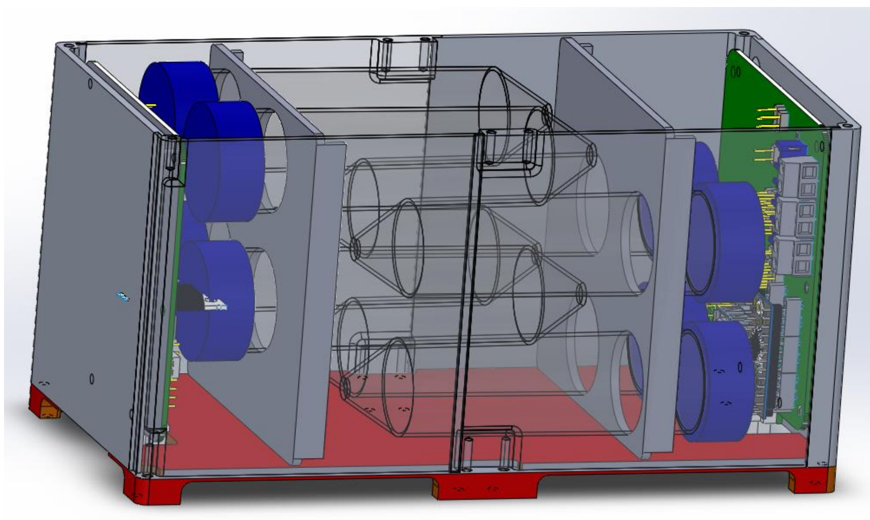

Figure 14-CAD model illustration of vial supports

Thermal Control System

The PeVaLab is housing a biological experiment where the thermal environment must be considered. There will be minor amounts of heat produced by system electronics, however it will be efficiently dissipated by the TangoLab cooling system. The individual CubeLab will not have an individually isolated control system. For the planned experiment, via discussion with the TangoLab head engineer that the TangoLab cooling system will be sufficient in maintaining sample viability. The amount of heat which is predicted to be present in the cube at any given time will not have an effect on the biological sample.

Communication System

The TangoLab will collect all data from experiments housed within it. Users with experiments on the lab will be able to receive data from their experiments continuously through the Customer Portal established by Space Tango Inc. The Customer Portal in combination with the systems open source software will allow the user to send commands to the experiments on orbit. This feature allows for continual iteration from the user to the experiment. The experiment will produce minimal data, the communications infrastructure in place will be able to support the amount of information exchanged.

TangoLab will communicate all uplink and downlink commands through the established links to and from the ISS. The ISS uses the Tracking and Data Relay Satellite System (TDRSS) to ensure continuous global communication with the ISS. Information is transmitted up to a one of nine geo-synchronous Tracking and Data Relay Satellites (TDRS); which then transmits down to one of two primary ground stations, if available. The two primary ground stations for TDRSS are White Sands Ground Terminal and Second TDRS Ground Terminal, both located in Las Cruces, New Mexico; collectively these two ground stations are more commonly known as White Sands Complex (Menrad, 2014). In the event neither of these ground stations are available, TDRSS will utilize an antenna on the Near Earth Network (NEN).

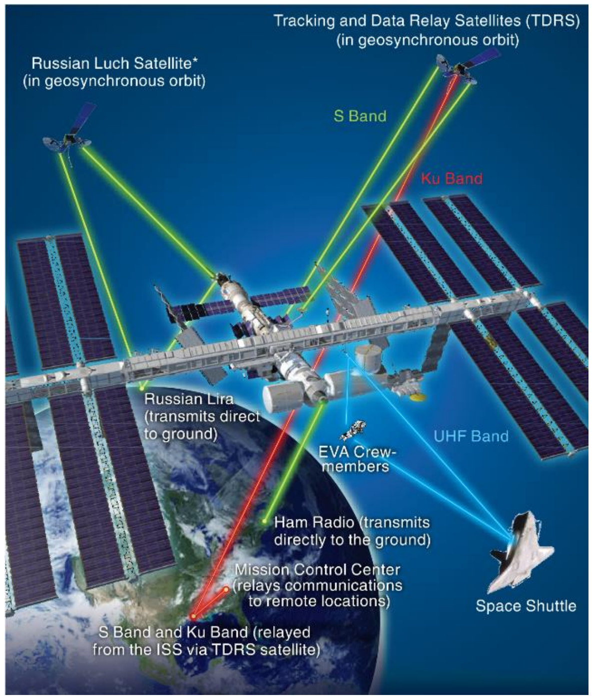

Figure 15-ISS and TDRSS communication structure

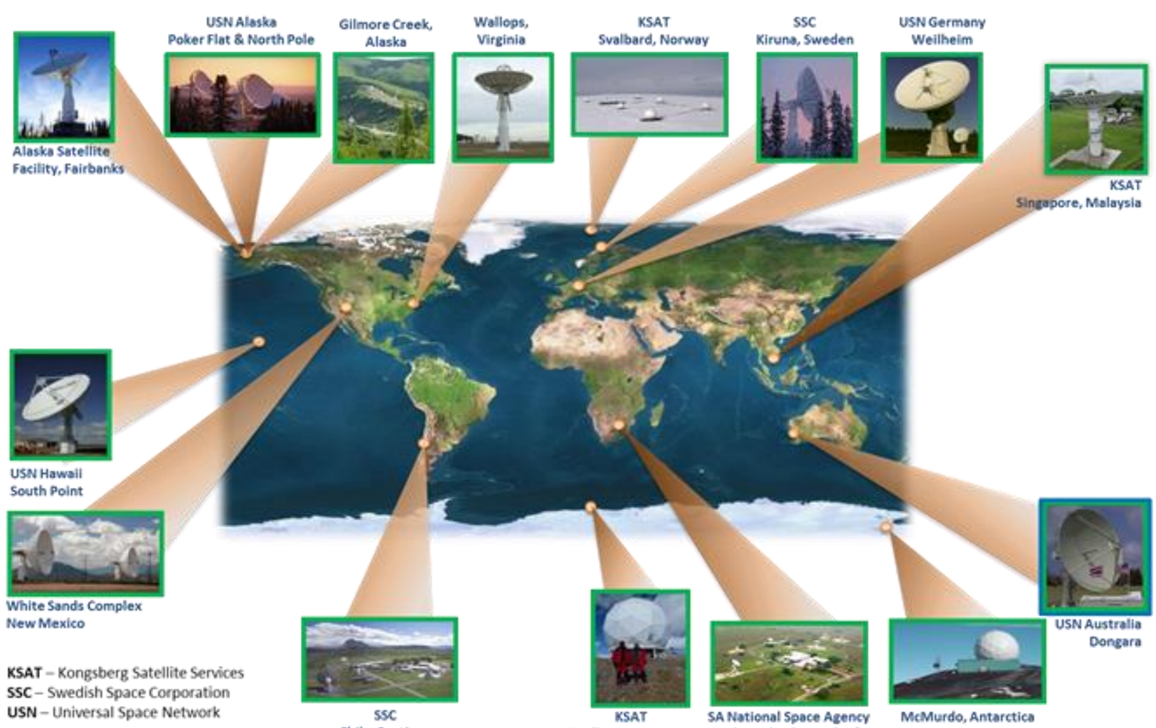

Figure 16-NASA's Near Earth Network

Ground Processing

The TangoLab will collect all information from the individual experiments. Existing ground station infrastructure, utilizing the TDRS satellites, will be leveraged to downlink information from the TangoLab. Once all information is received by a ground station, Space Tango Inc. will receive all data from ISS processing. Space Tango Inc. will be responsible for distributing data to affiliated customers.

Power System

The power system will be provided by the ISS for the TangoLab. The module will serve as the source of power for all cubes housed within it. The PeVaLab will utilize one of the allotted voltage levels from the TangoLab. The module provides three voltage source levels which each payload can utilize as needed. The PeVaLab is planning to leverage the 3.3 or 5-volt source from the TangoLab; either voltage source is sufficient and will be determined at a later date.

Observation System

The experiment cube will not contain an observation system within the cube. CubeLab's do have the option to enclose a means to view the ongoing research. The seeds however do not need to be viewed to make conclusion on-orbit. All visual and experimental analysis will occur after the seeds have returned from orbit. Visual observations of the seeds are not critical when concluding results; for this reason, an observation system was not designed within this cube. The Tango-Lab does have cameras within the module to ensure successful installation. Additional forms of observation will occur via the SpaceTango data logging system. This system will monitor the environmental temperature, altitude, and other factors which may induce experimental anomalies.

On Board Computer

The on board computer is an Arduino Mini. Using the Arduino based materials reduces the cost and is applicable to many scenarios. The microcontroller and data logger system is standard from Space Tango. Power to the system is achieved through a connector on the base of the cube. This connector also serves as an attachment point to the payload cards.

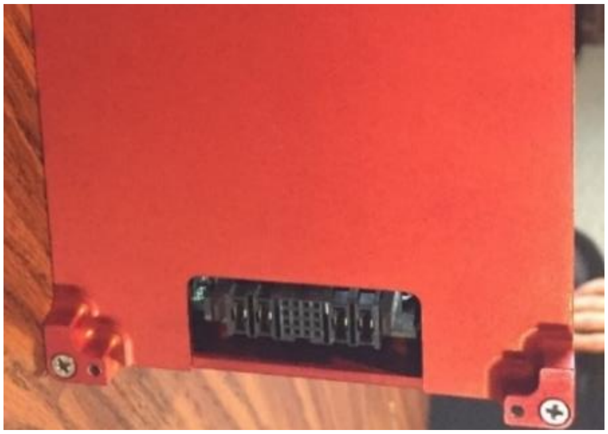

Figure 17-Connector to payload card on base of cube

Biological Sample Integration

C. roseus seeds will be provided by the School of Pharmacy at the University of Kentucky. The seeds will be counted and placed into sterile vials within the laboratory. Once in the vials, parafilm wrap will be used to seal the vials to inhibit excess moisture entering into the vials. After the seeds have been placed into the vials and sealed appropriately, they will then be transported to Space Tango Inc. There the vials will be inserted into the designed supports and furthermore into the CubeLab. The biological samples will then be ready for transport to the ISS.

CubeLab Integration

The CubeLab will be attached to a payload card for transport. The cube attaches via a connector on the base of the payload. The connector is a component on the electronics boards at each end of the cube. Although a 2U cube has multiple openings for connectors, only one is needed to ensure successful installation to a payload card. The payload card, containing multiple experiments, will travel to the launch site. The payload card will be installed by an astronaut upon its arrival to the ISS.

Figure 18-Base of CubeLab showing connection points to payload card

Figure 19-A 1U CubeLab attached to a payload card

Figure 20-Payload card with 1U CubeLab installed in TangoLab

Launch Vehicle

PeVaLab will be delivered in June 2016. This is when Space Tango Inc. has scheduled a flight to resupply the TangoLab and retrieve existing experiments. The cube is scheduled to be on the ISS during the second batch of experiments within the module. The rocket which Space Tango Inc. will utilize to resupply the TangoLab is undetermined at this time, but predicted to be a SpaceX supplied rocket. Launch provider selection is determined based on available launch vehicles at desired time of resupply.

Mission Logistics

Cube Assembly and Transportation

Two weeks prior to the delivery date established by the launch provider, Space Tango will assemble the cube and ensure proper functioning of all electronics. The seeds are not extremely time sensitive; however to minimize risk of inducing outside contaminants the seeds will be delivered in the sealed vials to Space Tango. The vials will then be fastened properly within the tube utilizing the designed support. The cube will then be transported to the delivery site using

FedEx Space Solutions. A unique transport plan will be established to prevent events which may disturb the cube assembly.

Delivery and Launch

Delivery will occur by the shipping provider to the integration facility. Upon arrival to the launch provider, the payload card will be stowed into the vehicle for delivery to the ISS. Launch services will then be coordinated by the launch provider.

On Orbit

Upon arrival to the ISS, crew will then install the payload card into the TangoLab. Space Tango Inc. will receive the status of the payload card installation to ensure a successful installation. Once the card is successfully installed, no uplink commands will be made to the CubeLab. The cube will monitor the health of the environment; this information will be retrieved at minimum once per day.

Return and Analysis

The payload card which holds the PeVaLab will be returned from the ISS approximately 6 weeks after being on orbit. Once the payload card has been returned to Space Tango Inc. all experiments will be quickly distributed to associated researchers. The seeds contained in PeVaLab will be planted immediately. Once these plants have reached a later stage of growth and leaf formation has begun, they then will be ready to begin analysis. The leaves will then begin undergoing the extensive testing to determine if the vinca alkaloids molecular structure has been altered or compound presence is increased due to microgravity.

Chapter V: Results and Implications

Results

To date, no results have been collected for this experiment. Results are dependent on the experiment residing on orbit aboard the ISS for approximately 6 weeks. Accessibility to the ISS is dependent on launch providers. The current projected launch date is June of 2016. This date falls after the submission of this thesis, therefore results will not be collected in time for submission. The expectation for this thesis was to ensure a functional design was established and that all conditions were achieved for the experiment requirements. Assembly procedure was established however could not be fulfilled prior to thesis completion due to the shelf lifetime of the biological product.

Implications

The results of this research are largely to grasp a better understanding of these compounds after exposure to microgravity. While the expectation may be to discover that microgravity yields more compound production, other biological experiments have yielded results far beyond anything expected. Research such as this has a great opportunity to provide insight to these compounds and potentially provide results which the human mind could never expect.

Protein crystallization is an area of study in microgravity that is undergoing extensive research in microgravity. Even as far back as the shuttle mission, protein crystals were an area of interest for the unique results when exposed to microgravity. Protein growth experiments were placed on the STS-26 and STS-29 shuttle mission in 1988-1989; these proteins had undergone extensive laboratory testing prior to the research in microgravity. When comparing the results of the best Earth-grown crystals to those on the shuttle, there was no comparison. The shuttle crystals were larger, more uniform in morphology, and yielded data to significantly higher resolutions.

Space grown cystals also are more highly ordered at the molecular level than Earth-grown counterparts (DeLucas, et al., 1991).

Research in microgravity has the potential to have a substantial impact on the understanding of microgravity on vinca alkaloids. This experiment also serves as a precedent for research of its kind in the future. Space Tango Inc. has worked to provide a more accessible and economic means to undergo microgravity research. This research will illustrate the availability of the TangoLab and the features which it offers to researchers.

Chapter VI: Conclusion and Future Work

Conclusion

The opportunity microgravity offers to the understanding of biological processes will continue to advance. More researchers every year gain an interest in pursuing research aboard the ISS. Companies like Space Tango Inc. will continue to develop platforms which are more accessible and desirable to researchers to pursue their experiments. Companies are also continually working to provide more frequent access to space; between launch providers and platform providers the opportunities will continue to grow.

Specifically, with the research defined in this thesis, cancer treatment has great potential to improve. As more research is continued in microgravity on vinca alkaloids, more effective treatment has the opportunity to emerge. Space Tango Inc. works daily with researchers to ensure they now have the equipment and accessibility to space needed to develop new results.

Future Work

The biological sample used will undergo multiple flights on the ISS under different conditions. At the current time there have been two phases defined, however it is expected to incur more. The experiment phases are developed to determine at what stage of seed development does microgravity have an effect on vinca alkaloids, or if there are effects at each stage of growth to determine the differences at each stage. During each phase the payload will be returned to Earth for analysis, however it is predicted during later phases some on board analysis will be completed.

Experiment Phase Timeline

Phase 0 – Initial Experimental Demonstration

This phase will be used as a means to retrieve baseline data for how this seed type reacts in microgravity. These seeds will be housed in the microgravity environment before any later plant development has occurred. The design for this thesis will be used to carry out this phase of experimentation.

Phase 1 – Later growth experimental design

Phase 1 will heavily depend on the results from phase 0. This phase was developed in the event no change is found to occur in seed development during the baseline phase. If not change occurs, the seeds will then be installed the same as during the previous phase and then at some defined time aboard the ISS, moisture will be induced into the system. Moisture exposure to the system will permit the seed to begin germination. After germination has begun, seeds will be returned to finish growth on Earth.

Phase 3 – Continued Research

Once the results of the phases above have been analyzed, further research will continue. Further experiments also present the opportunity to consider other potentially attributing factors of change, i.e. duration of exposure.

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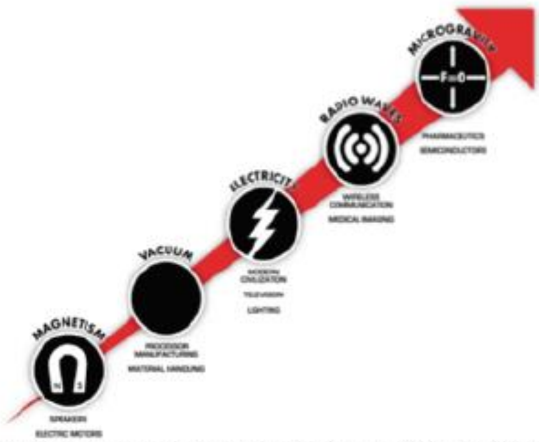
Appendices

Space Tango Overview

Space Tango

Innovating in Space for Solutions on Earth

Every time humanity has harnessed a new physics environment innovations have been created. This has precedence from magnetism through radio waves; now microgravity is the environment to be harnessed. Space Tango Inc. works with customers to design, fly and operate automated systems that range from R&D experiments to manufacturing that continues this trend.



This platform allows automates critical operations, facilitating multiple experiments about the size of a tissue box, called CubeLabs, to run simultaneously. This reduces the amount of required astronaut interaction, which in turn lowers costs and complexity while increasing scalability. Each customer will be able to interact with and retrieve their data via our online customer portal that enables near real-time access to their payload.

Target markets include but are not limited to pharmaceutical, biomedical, plant biology and materials manufacturing. The TangoLab-1 uses a Payload card architecture that the CubeLabs plug onto and themselves are flown to and from the ISS. Space Tango Inc. is dedicated to designing, developing and commercializing the next generation of platforms that make major discoveries possible.

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CubeLab One Pager

Space Tango

CubeLab

Design Standard Enabling Research on the International Space Station

The CubeLab standard outlines the requirements to interface with the TangoLab-1. A full Interface Control Document will be released in the spring of 2016 in preparation for launch of the facility.

Connectivity: While on ISS TangoLab-1 is networked to the Earth via an Internet connection; users will be able to receive data from their experiments continuously through our Customer Portal (coming Summer 2016). This coupled with the systems open source software allows you to send commands to your experiments on orbit allowing continual iteration.

Process Flow: Experiments connect to specifically designed payload cards which themselves are flown to and from the ISS. Once on ISS, these cards are installed and provided power and Internet connections from the TangoLab-1 facility itself.

The Figure Above Shows a Single 1U CubeLab Attached to a Payload Card Installed within the TangoLab1 Platform

Volume: 101.6mm cube, not including separation feet
Mass: up to 1.25 Kg
Power: 7.5 Watts total; provided 3.3, 5 and 12-volt power rails
Data: 255 Byte Packets at 1 Hz (1MBaud 3.3V UART)
Provided Services: Power Telemetry, Imaging, Customer Portal
Standard Kits: Cell culturing, plant, mold / bacteria growth and tissue diffusion model CubeLabs under development

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